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Report SE-93-01

DESIGN OF A FLEXIBLE ROBOTIC ARC WELDING SYSTEM TASK III

VOLUME I: SYSTEM OVERVIEW

Manufacturing Methods And Technology
Project No. 6888603, Task III

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30 September 1993

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Final Technical Report for MMT Project 6888603, "Robotic Welding" covering Jan 88 to Dec 88. Third of four technical reports for RIA contract number DAAA08-87-C-0096.

94-30804

Approved for public release; distribution unlimited

SCIENCE AND ENGINEERING DIRECTORATE
ROCK ISLAND ARSENAL
ROCK ISLAND, ILLINOIS 61299-5000

94 9 26 069

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): SE-93-01
6a. NAME OF PERFORMING ORGANIZATION: Babcock and Wilcox CIM Systems; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: SMCRI-SEM-T, Rock Island Arsenal
6c. ADDRESS (City, State, and ZIP Code): P.O. Box 785, Lynchburg, VA 24505	7b. ADDRESS (City, State, and ZIP Code): Science and Engineering Directorate, Rock Island Arsenal, Rock Island, IL 61299-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: Contract DAAA08-87-C-0096
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
DE 62	6888603		

11. TITLE (Include Security Classification)

Design of a Flexible Robotic Arc Welding System, Task III, Volume I, System Overview

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Jan 88 TO Dec 88	1993 September	50

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Welding, Arc Welding, Robots, Robotics, Systems Engineering, Flexible Welding Systems, Computer Integrated Manufacturing
13	08		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report represents the 100 percent completion of the technical data package (TDP) for Task III of the Flexible Robotic Arc Welding System. The system design was developed to allow a diverse group of steel weldments to be fixtured, preheated, robotically arc welded, manually inspected, repaired, and moved by an automatic guided vehicle throughout the welding system. The system is monitored and operated by a systems computer in a distributed control environment. The two welding robots are individually controlled by their own robotic controller but downloaded from the systems computer depending on the bar coded information that follows the fixtured weldment mounted on universal pallets. The report consists of three volumes of design specifications with a fourth volume of technical supporting information that will be supplied upon specific request only.

DTIC QUALITY INSPECTED

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified	
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DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

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1. EXECUTIVE INTRODUCTION

The Flexible Welding System (FWS) is a totally integrated welding system for the gas metal arc welding (GMAW), handling and inspecting of Rock Island Arsenal (RIA) weapons components (refer to Figure 1). The System design was developed to automate the manufacture of candidate weldments. A primary design consideration was the need to increase quality and consistency while reducing and improving control over work-in-process. A second factor of importance in the design of the System was to provide manufacturing flexibility. This ensures that the System will be capable of producing components of new weapons systems well into the future. The overall design philosophy was to incorporate proven technologies necessary for a reliable system.

The FWS incorporates specialized part fixturing, an Automatic Guided Vehicle (AGV) for handling, an automated furnace for preheating, two robots for welding, accumulator racks for storage, and semiautomatic inspection and repair (I/R) stations. A distributed control system is used with a supervisory computer system that coordinates the microcomputers and programmable logic controllers (PLCs) used for individual workstation control.

The scope of the FWS design is to provide the capability of handling the weapons components shown in Table 1 at the throughput rates defined, as well as the capability to handle different weapons components in the future. For design purposes, the weldments were grouped into two families, "small" and "large". Small parts are the M1, the M1A1, the M140, and the M178; the large parts are the HIP-1, the HIP-2, the M39, the XM291-R and the XM291-C. These selected weldments encompass a wide range in terms of size, weight, and cycle time. This, along with the necessary control system flexibility and foresight, ensure that similar parts can be processed in the future without requiring major reconstruction of the System.

1. M-1 Cradle Weldment (P/N 12274298)	15 pieces/month
2. M1A1 Cradle Weldment (P/N 12304681)	30 pieces/month
3. M-140 Cradle Weldment (P/N 8449307)	10 pieces/month
4. M-178 Cradle Weldment (P/N 1159327)	25 pieces/month
5. HIP-1 (XM183 without top and bottom plates) Cradle Weldment II (P/N 84J2003)	20 pieces/month
6. HIP-2 (XM183) Cradle Weldment II (P/N 84J2003)	20 pieces/month
6. M-39 Bottom Carriage (P/N 12008380-E)	13 pieces/month
7. XM-291 Rotor Weldment (P/N WTV-F-31239)	20 pieces/month
8. XM-291 Cradle Weldment (P/N WTV-F-31992)	20 pieces/month
TOTAL	**173 pieces/month**

Table 1. Selected RIA weldments

Several computer-based simulations of the FWS were performed during Task II using different part mixtures and processing assumptions (for further details refer to the Task II report(2)). The average throughput for 98 of these simulation runs was 231 weldments/month; which is an additional 34 percent greater than the required capacity. This ensures that the required throughput rate can be easily achieved utilizing one shift of operation.

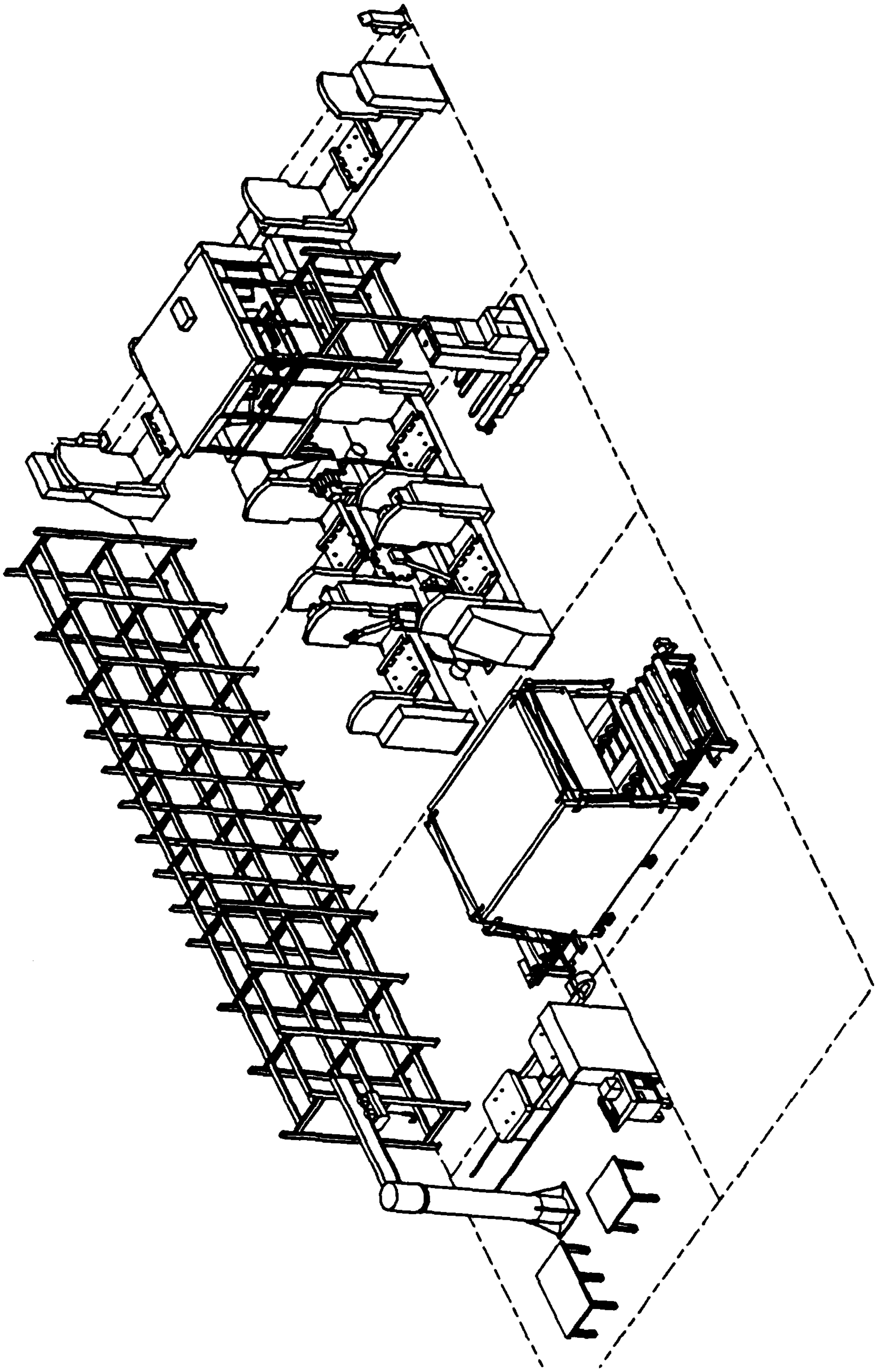

Figure 1. The Flexible Welding System

1.1 Statement of Work

The contract was divided into three main tasks. The goal of Task I was to provide three basic conceptual designs for the FWS and define the enabling technologies which would then provide the basis for the system design. The results of this task are contained in the task ending report, entitled "Design of a Flexible Robotic Arc Welding System, Task I"(1). Task II consisted of completing 38% of the Technical Data Package (TDP) in which the selected concept from Task I was refined and detail designed. In addition, the Training Plan section of the report served as a final deliverable to the contract. These results were documented in the report, "Design of a Flexible Robotic Arc Welding System, Task II"(2). Task III comprised completion of all aspects of the final design for the FWS and the design and specification of a production planning system. The production planning system design was included in the contract as Option 1 of Task III. Task III's final deliverable is the System Overview, the design specifications, a Drawing Package, and a Supporting Information document, which comprise the TDP. The TDP incorporates the design work from Task II and serves as the final, complete design package.

1.2 Report Organization

The TDP report is organized in three volumes. This volume, the System Overview, which contains an overview of each task, an explanation of the System highlights, an overall System description, and a process description; and the Design Specification volumes, which consist of twelve chapters for each main category encompassing all areas of the FWS design.

<u>VOLUME 2</u>

1. Load/Unload Station
2. Preheat Furnace
3. Automated Guided Vehicle
4. Accumulator Racks
5. Fixtures
6. Robot Workcell
7. I/R Station

<u>VOLUME 3</u>

8. Control System
9. Control Room
10. Production Planning
11. Safety Plan
12. Site Plan

Each chapter, where applicable, contains several sections, with each section being an individual design specification. Each design specification is formatted to function as a

stand-alone document containing all the necessary design information for that particular functional area incorporating, when applicable, the following sections:

- Overview
- System Descriptions
- Process Description
- Operator Interface
- Specifications
- Facility Requirements
- Inputs and Outputs (I/O)
- Flow Charts
- References
- Reference Drawings

1.3 Drawing Package

A drawing package is part of the final TDP. The drawing package consists of design drawings of any component that is a custom design, or any modification to an off-the-shelf design. In addition, drawings for the site plan are included. These site plan drawings consist of demolition drawings, electrical, structural, and mechanical drawings, as well as, equipment location drawings. The drawing label consists of a four digit number, following the format CIMXXXX (i.e. CIM1000). The drawings are numbered between 1000 and 1099 for the mechanical drawings, and between 1100 and 1199 for the electrical drawings. The list of included drawings is shown below:

DRAWING NO.	DESCRIPTION
Mechanical Drawings	
CIM1000	M1 Holding Fixture
CIM1001	M1A1 Holding Fixture
CIM1002	M140 Holding Fixture
CIM1003	M178 Holding Fixture
CIM1004	Accumulator Racks
CIM1005	HIP Holding Fixture
CIM1006	XM291 Holding Fixture
CIM1007	M39 Holding Fixture
CIM1010	Universal Pallet
CIM1020	Positioning Table Top
CIM1021	Hydraulic System Piping Diagram
CIM1030	Robot System Positioning Tables
CIM1031	I/R Station Positioning Tables
CIM1040	Foundation and Slab Plan
CIM1041	Catwalk Framing
CIM1042	Main Floor - Demolition Plan
CIM1043	Main Floor - Exhaust and Piping
CIM1050	Preheat Furnace

Drawing No.	Description
CIM1060	Transfer Shuttle
CIM1070	Equipment Layout
CIM1071	Weldment Position Numbering
CIM1072	Foundation Layout
CIM1090	Robot Workcell
Electrical Drawings	
CIM1104	Accumulator Wiring
CIM1120	Clamping Schematic
CIM1130	Robot System Positioning Tables
CIM1131	I/R Station Positioning Tables
CIM1132	I/R Station
CIM1140	Demolition Plan
CIM1141	Main Floor - Power and Control Plan
CIM1150	Preheat Furnace
CIM1160	Load/Unload Terminal
CIM1170	Control System Interconnection
CIM1171	Interconnection Reference Designators
CIM1180	Control Room Layout

2.0 SYSTEM DESCRIPTION

The FWS (also refered to as the System) will be located in the REARM facility, Building 212 West, between columns 12.5 and 11 and centered around column line C. The area will encompass 7 of the manual weld booths currently in the building; (nos. 6, 7, 8, 9, 16, 17, and 18). The System will incorporate all of the available floor space, leaving the 8 foot aisles on the north and south ends. In addition, portions of the catwalk within the workspace will be utilized to hold control cabinets and power supplies.

The System consists of several distinct functional areas (refer to Figure 2). These are: the load/unload (L/U) station, the AGV area, the preheat furnace, the robot system, the accumulator racks, the inspection/repair (I/R) area, and the control room.

L/U Station

The L/U station, where components enter and exit the System, consists of a transfer shuttle, a jib crane, the L/U operator station, and the layout area (refer to Figure 3). The transfer shuttle consists of two carts with rotary turntables. The carts move in tandem with each capable of servicing the AGV access point. The carts serve as stations for manual part fixturing prior to entering the System and part de-fixturing upon leaving the System. The parts and fixtures are manually handled within this area using the electric hoist jib crane. All interfacing with the supervisory computer, and all local control of the transfer shuttle are performed at the L/U operator station. The layout operations are performed within this area using RIA supplied targeting fixtures.

AGV System

The material handling for transporting weldments between the various stations will be performed by an Interlake forklift-style AGV (refer to Figure 4). The selected AGV provides the necessary accuracy and payload while providing the vertical lift necessary to store the weldments three high in the accumulator racks. The AGV will follow guide wires embedded in the floor and will communicate with the supervisory computer for dispatch orders using radio frequencies. Every part placement location utilizes a tapered pin arrangement to mate with bushings on the universal pallet to correct for AGV positioning misalignment. In addition, a bar code reader attached to the AGV will be used to identify individual fixtures and maintain proper part tracking within the System.

Preheat Furnace

The preheat furnace provides conveyorized movement from the charge to the discharge end for automated weldment handling during the preheat function (refer to Figure 5). The preheat furnace allows the capability to handle all selected parts, encompassing a wide range of sizes weights and soak times. The furnace allows several parts to be batched at one time, including mixtures of part types. This ensures that the System will have preheated parts available for robotic welding.

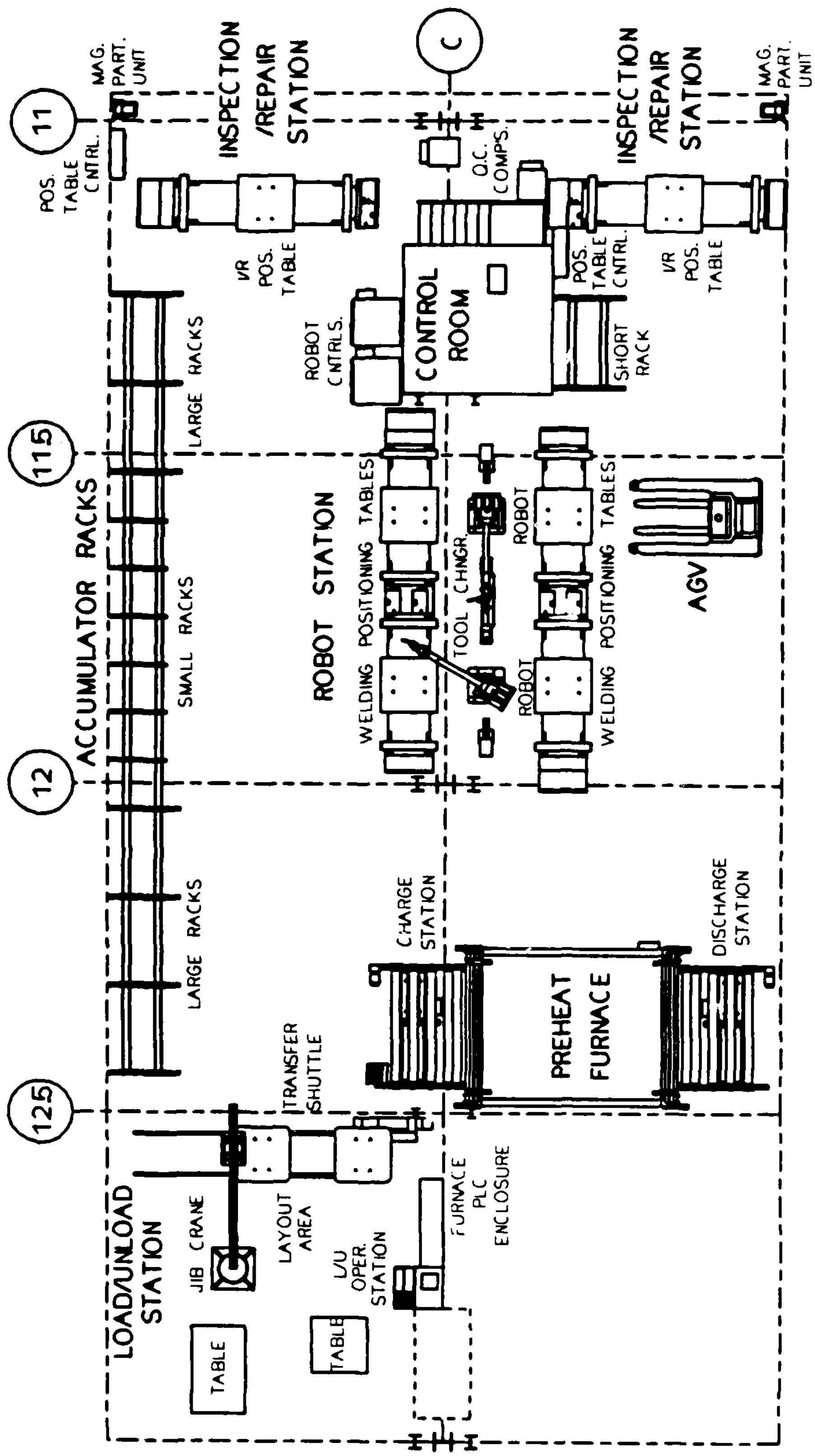

Figure 2. System functional areas

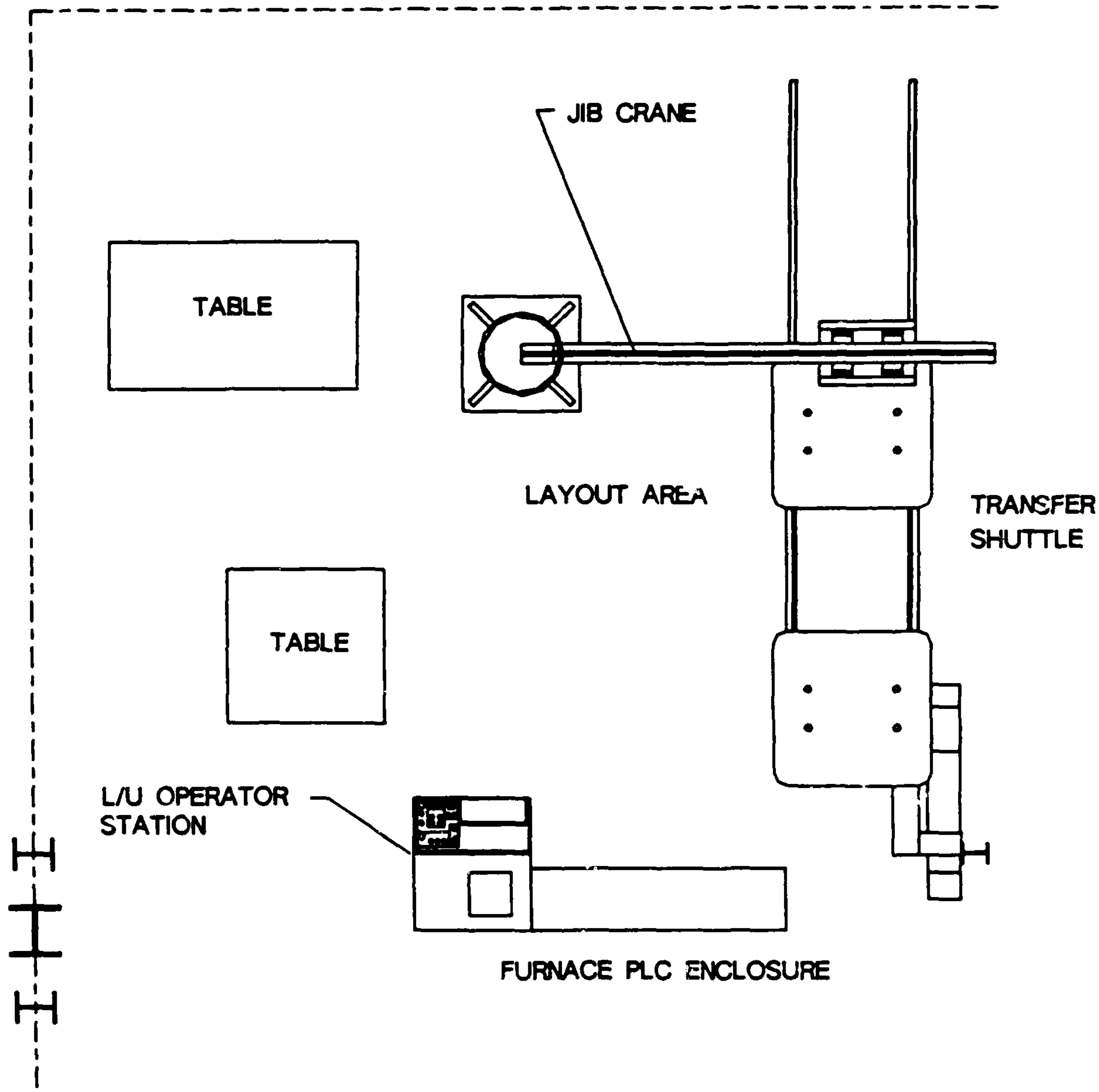

Figure 3. L/U station

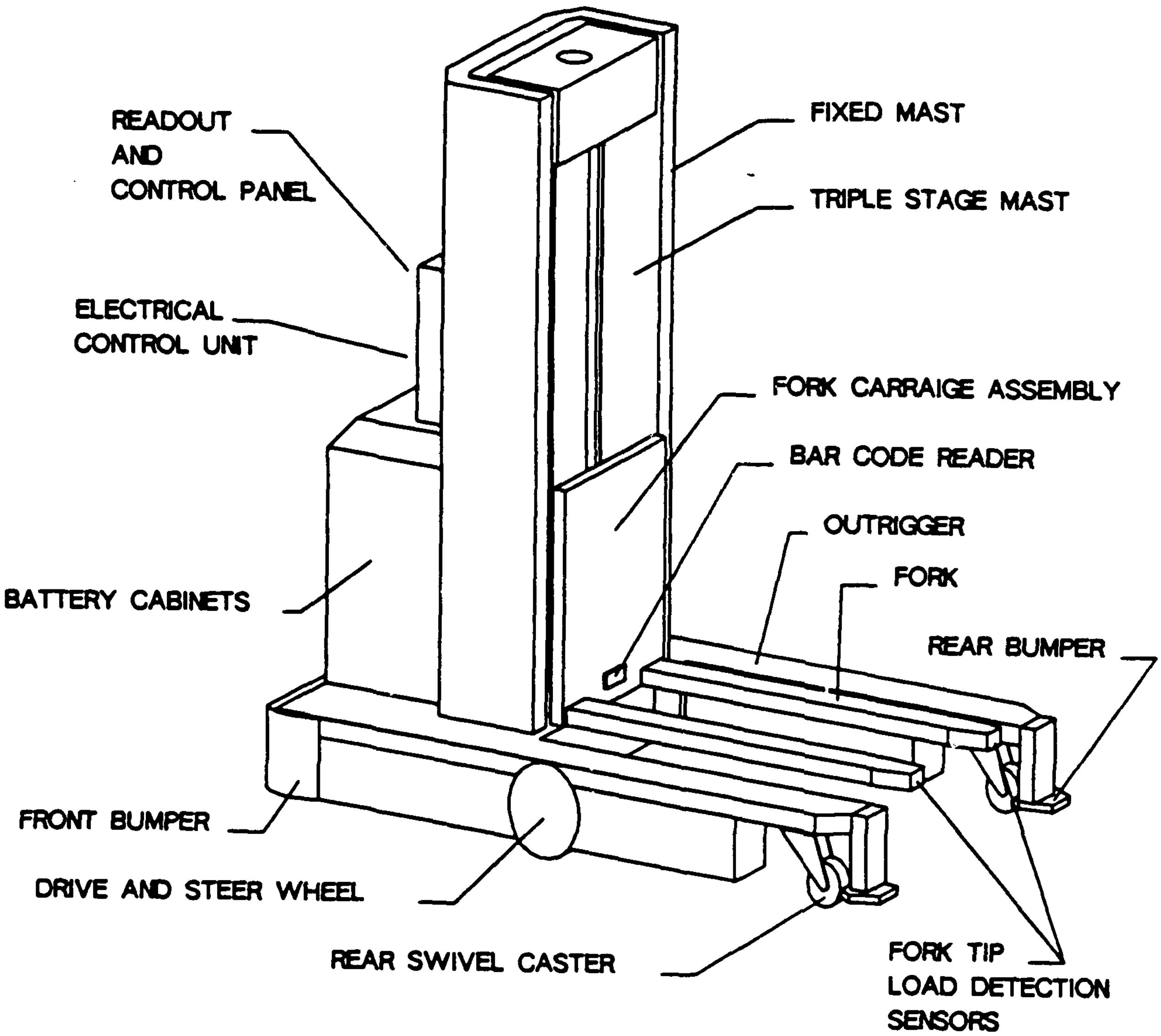

Figure 4. AGV system

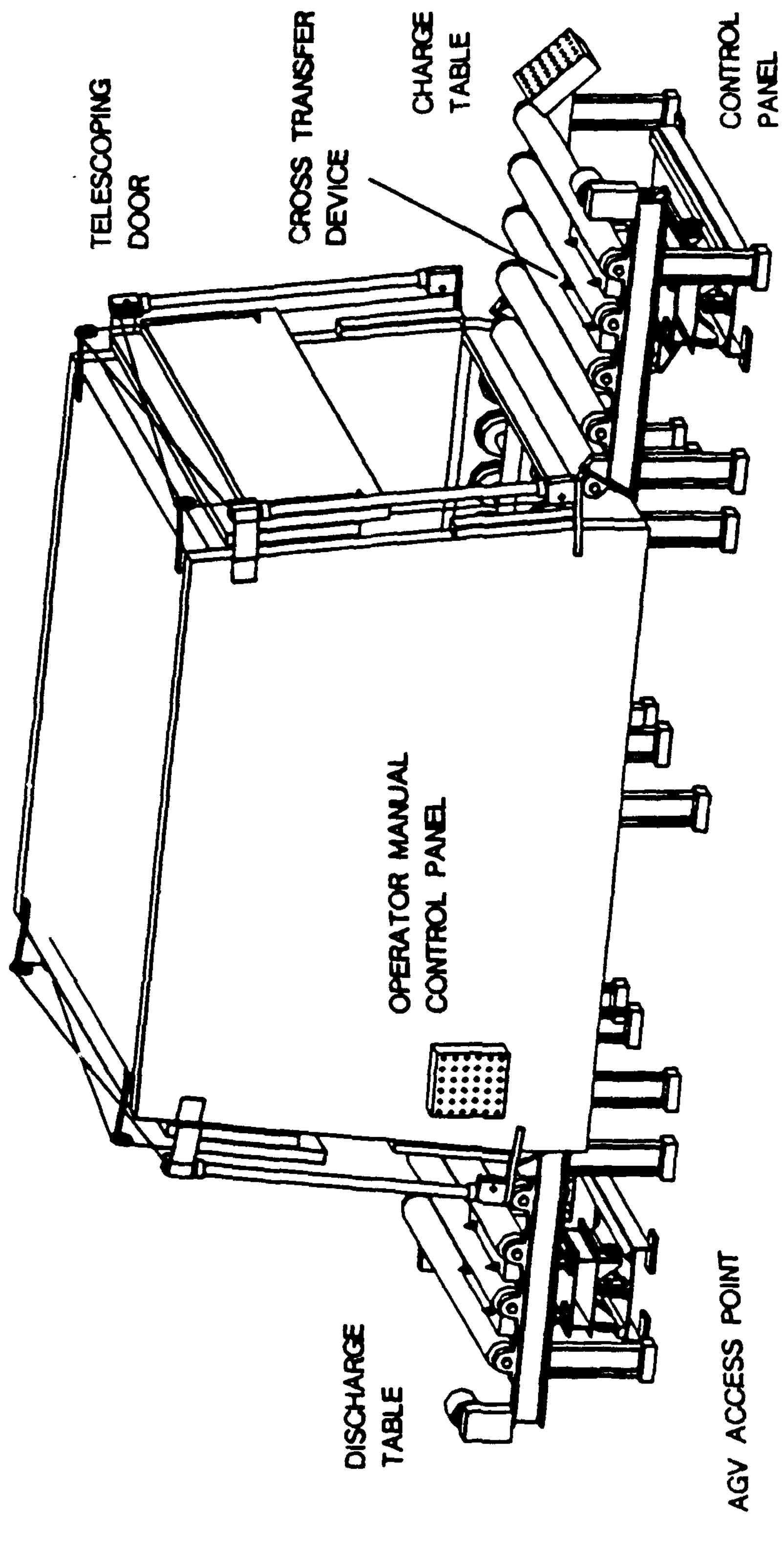

Figure 5. Preheat furnace

Robot System

The robot system is based upon two Cincinnati Milacron T3-646 robots. Each robot will perform Gas Metal Arc Welding (GMAW) on the weapons components using touch sensing and through-the-arc seam tracking. Two positioning tables per robot are used to position the parts for welding in the flat position (refer to Figure 6).

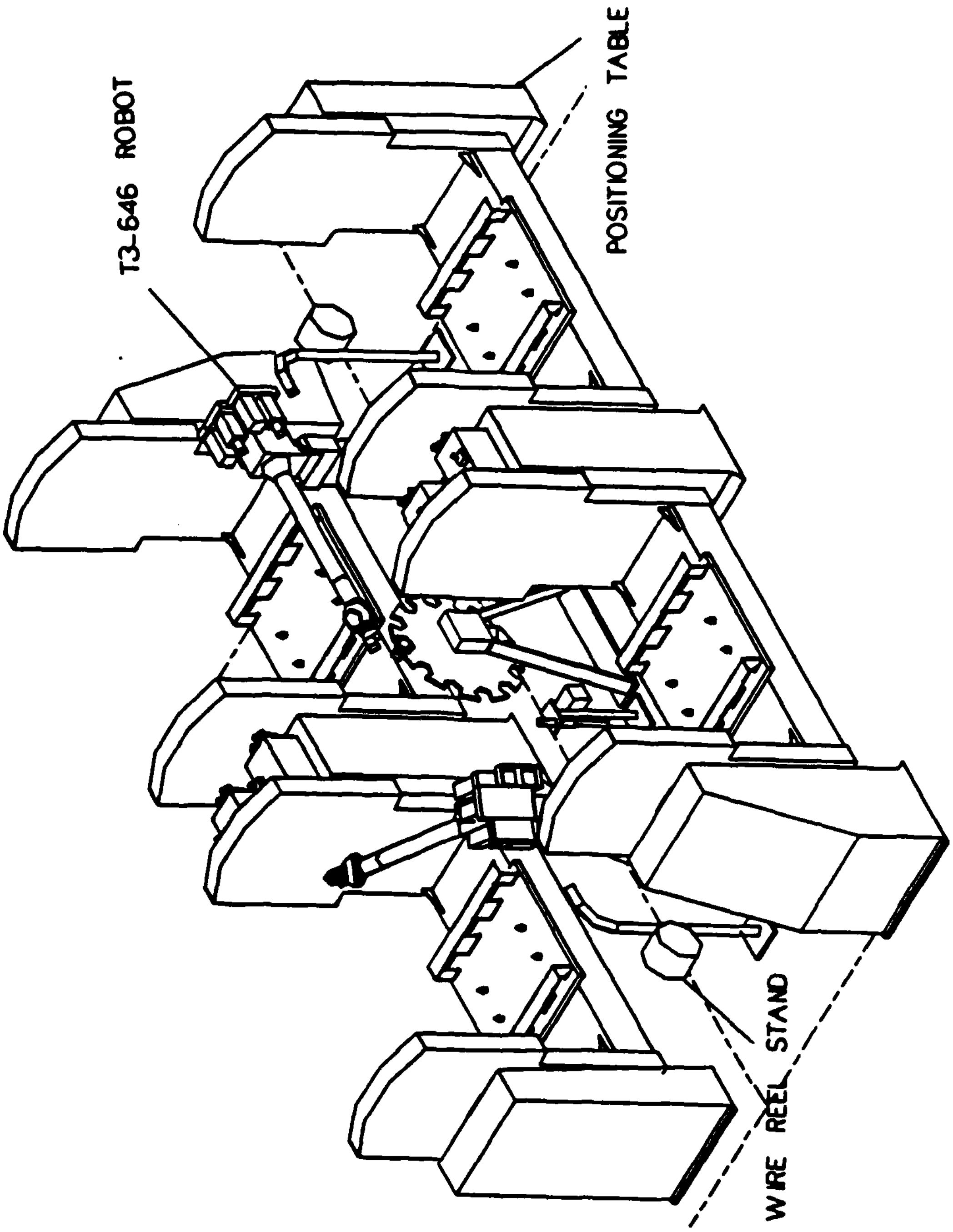

Figure 6. Robot system

Accumulator Racks

The accumulator racks are used to store fixtures and weldments within the System (refer to Figure 7). These racks allow parts to cool after welding and provide temporary storage for empty fixtures. The 38 racks in the System will accommodate surges in production to prevent bottlenecks.

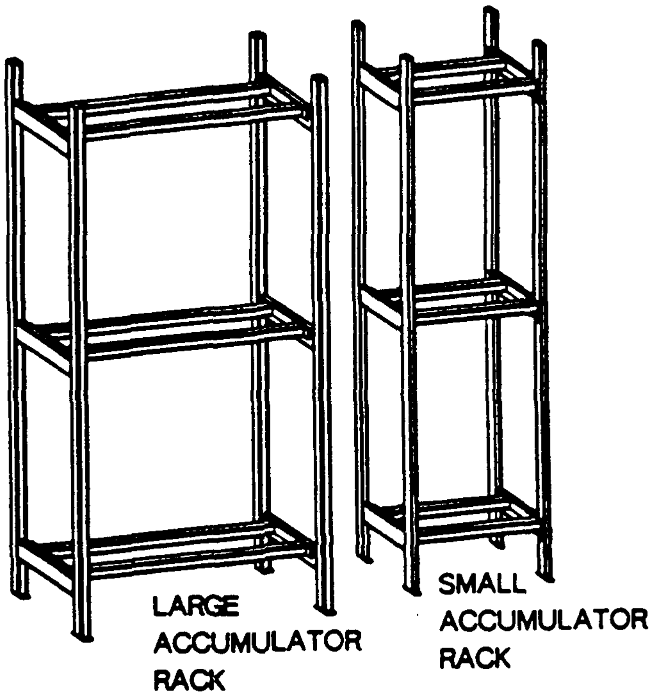

Figure 7. Accumulator racks

I/R Station

The visual and magnetic particle inspection, as well as the weld repair functions will be performed at the I/R station (refer to Figure 8). This station accepts automatic part loading from the AGV, provides semiautomatic weldment manipulation with the positioning table, and utilizes a graphics-based computer interface for defect logging and I/R sequencing.

Control Room

The control room provides the supervisory computer operator the ability to monitor the entire cell operation from one location. Situated within an operator console will be the Vista terminal, video camera monitors, E-stop switches, hard-wired controls and indicators, the AGV computer terminal, and the intercom-type communication system (refer to Figure 9). The control room is designed using human factors engineering principles and provides a climate controlled environment for the computer equipment.

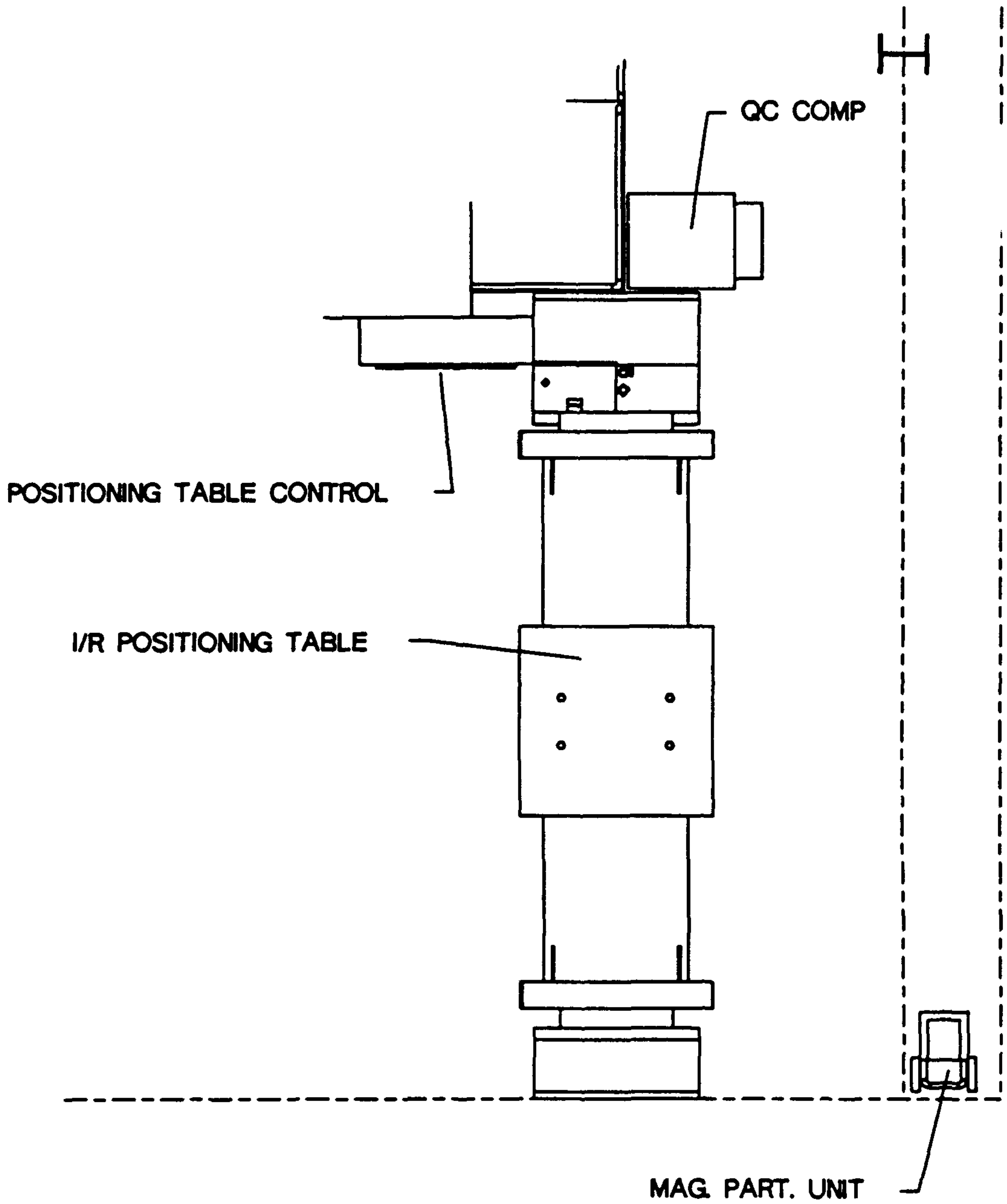

Figure 8. I/R station

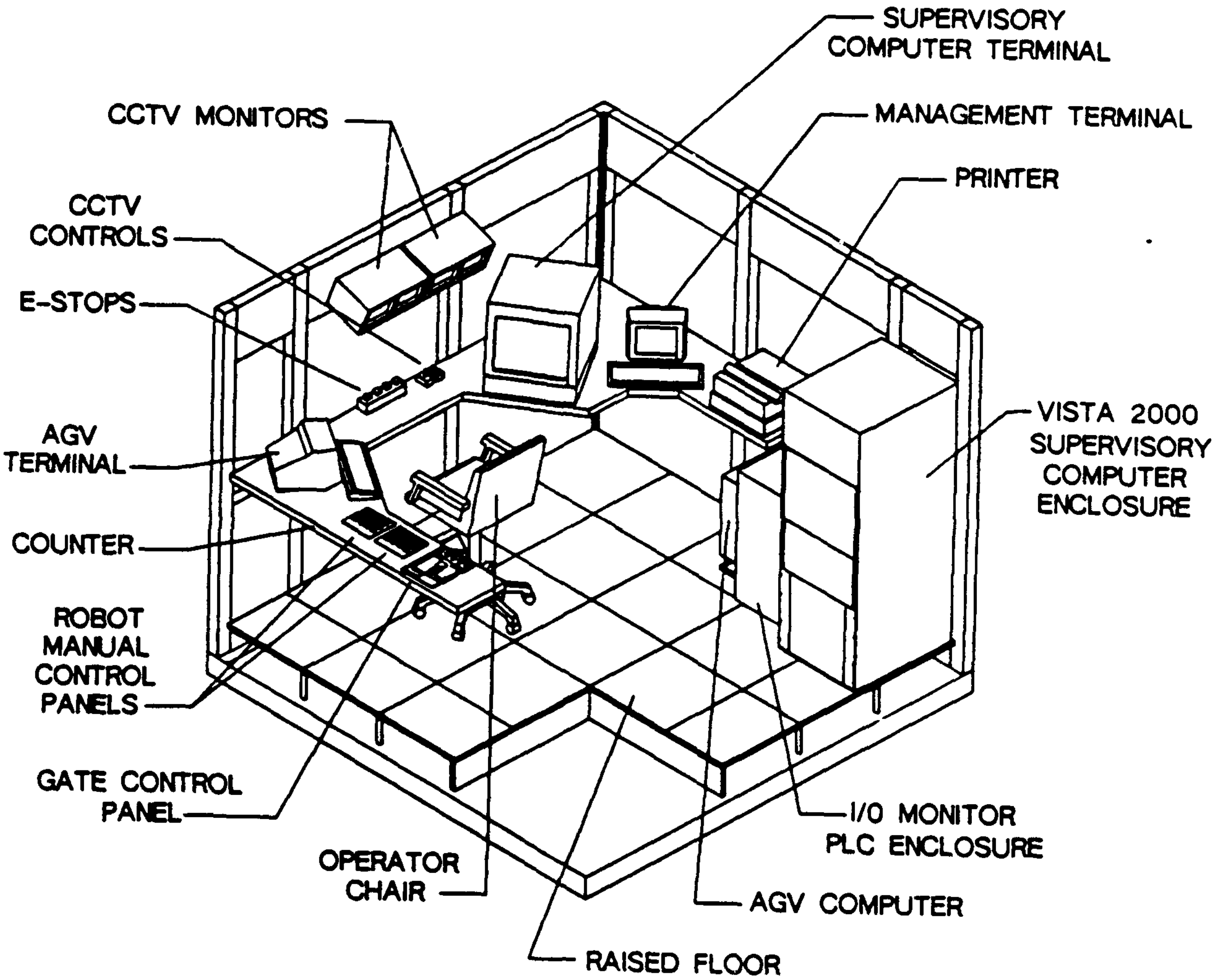

Figure 9. Control Room

2.1 System Highlights

The FWS is a highly integrated system utilizing the latest in proven technology. The combination of a well developed control methodology and a human factors based modular design, provide many unique features and important benefits. These elements were developed to improve, ease, and simplify the management, quality control, and operation of the FWS. The key features are outlined in this section.

Simplified Production Control

The System is not dependent on any complex scheduling device. The part sequencing is dictated by the order the parts are introduced to the System. Parts can be processed in lot sizes as small as one, requiring no System setup or change-over time. However, system throughput is maximized by introducing a logical sequence of relatively small batches of different part types. This type of scheduling provides a "shop floor" approach to ease the integration of the System into the overall factory.

To compliment this approach, the computer-based production planning system will allow different scheduling scenarios to be simulated before actual production cycles begin. This software will provide the capability to simulate different part mixtures or new part types, as well as the capability to update the parameters to reflect "real world" conditions. The software will follow a simple menu-driven format and will not require a computer specialist to operate.

System Flexibility

The System was designed with the features necessary to meet the changing demands of the production environment. The most important feature is the ability to incorporate new parts in the future without reprogramming or redesigning the System. This prevents the FWS from becoming ineffective, as the current weapons systems are phased out of production, and allows new weapons systems to be competitively produced with accountability of cost, production, and quality data. Additional elements of flexibility are:

- The FWS has the capability to operate on a multiple shift basis. This will allow surge capacities to be met as well as increasing production needs.

- Normal System operation requires trained, but not highly skilled operators. The graphics-based operator interfaces and well-developed training plan will eliminate the dependence on critical personnel.

- The FWS has the capacity to store a limited amount of "active" fixtures within the System for efficient processing. Several of the necessary fixtures for the part types being processed at that time can be stored in the System to minimize the reliance on support personnel.

- The robot system has the capability to automatically change torches. Torch changing allows the use of many torch configurations for different part types or areas of the same part. The torch changer also allows the use of a pyrometer to measure weld seam temperatures prior to welding.

- The System design is modular. This will allow improvements in technology to be incorporated into the System on an as-needed basis (i.e. off-line programming of the robot workcell, vision-based welding, interfacing to outside computer networks, etc..)

- The System has the ability to operate in three modes; automatic, semiautomatic, or manual. This will allow the operators to gain confidence in the System and help to ease the integration into the current production environment. In addition, recovery from fault conditions can be performed with minimal downtime by allowing operator intervention.

- The developmental capacities of the supervisory computer allow the actual production experience to be incorporated into the control logic (i.e. weld sequencing can be easily modified, preheat times and cool down times can be changed).

Quality Improvements

By tracking each weldment as it is processed through the FWS, a full audit trail will be developed for each part. This audit trail will include the times required for each operation, the inspection results, the repair rates, the location of each defect, the weld times, and other pertinent data. This data can then be accessed by quality control (QC) personnel for evaluation and manipulation using the resident statistical process control (SPC) capabilities. The results can then be used to pinpoint problem areas that need improvement. In addition to the use of SPC data, the System will improve the overall quality of the products because of the consistency gained from robotic welding and operator-guided inspection processes.

Safety Features

The system incorporates many safety-related devices such as fences with interlocked gates to prevent unauthorized access, warning signs to inform and alert personnel tc potentially hazardous actions or areas, light beams and floor mats to prevent inadvertent entry into an area with "active" equipment, and emergency stop (E-stop) buttons to deactivate equipment if a hazardous situation presents itself. The careful integration of these elements into the System will help to promote a safe working environment without hindering production. An additional benefit of a closely followed safety plan for this System is the protection of the equipment itself.

Productivity Improvements

The design, along with developed time-study information has been computer simulated to aid in determining the System throughput. Analysis of this simulation has determined that the required monthly throughput (as shown in Table 1) will be exceeded. This estimate was developed conservatively and would be expected to improve after the System achieved full

production status. The overall System is more productive than the current manual method for several reasons, including:

- Placing all preheat, welding, inspection, and repair operations within the allocated workspace under computer control will alleviate problems with work-in-process, bottlenecks, defect tracking, and general part flow.

- The inspection times should improve significantly as the process is developed. This is due to several factors, including: the use of a positioning table for all inspection/repair (I/R) functions to minimize the material handling, and the use of a computer-aided, graphics-based inspection device to increase the efficiency of the I/R function.

- The use of the Vista's logic capabilities along with the capabilities of the robot controller will allow efficient sequencing of welds, proper part temperature monitoring, and the ability to utilize parts on both positioning tables for maximum arc-on time.

All of these factors combine to make a state-of-the-art production facility utilizing the latest in proven technology. This System combines many high-technology features that have been proven in independent operations and workcells but that have not been integrated and coordinated into a full-scale system.

3.0 SYSTEM OPERATION

For purposes of describing the normal operation of the System, this section will present, in a walk-through manner, the processing of a generic small part. The description will focus on the operator interfaces and will follow an ordinary part flow as shown in Figure 10.

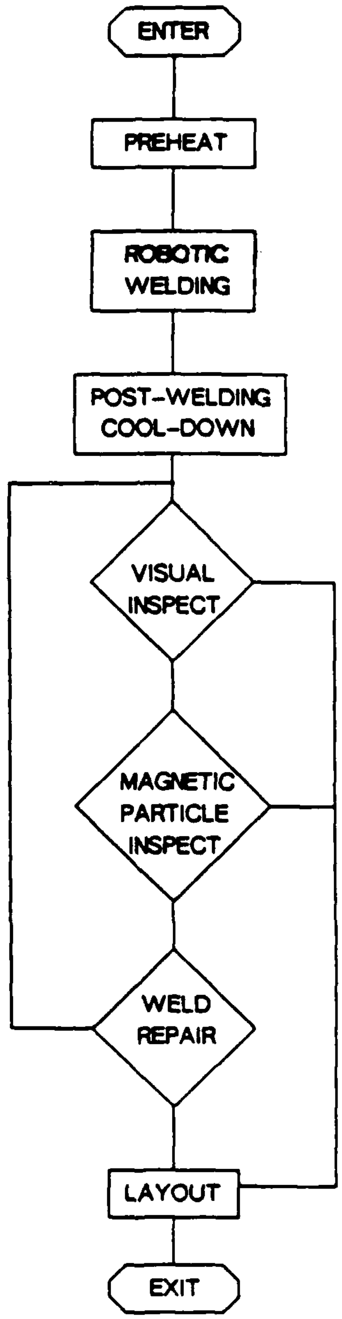

Figure 10. Generic part flow chart

This section will mention pertinent control details to clarify the manner in which the control system will operate. These details will include an explanation of certain important records (the supervisory computer uses Record Management software to store and manipulate tables of data called records), and tags, which are used to handle data, both numerical values and text strings. For simplicity, the complexities involved with controlling the System when processing many different types of parts will not be discussed.

The complete details of the supervisory control system are contained in the Supervisory Control System design specification in Chapter 8, Volume II. In addition, the details of individual station control are contained in their respective design specifications under the process description or local control headings.

3.1 Process Description

A tack-welded part is brought from outside the System to the L/U station. The L/U operator must determine if a transfer shuttle station is open for part loading and if an appropriate empty fixture is available, before fixturing the part at the transfer shuttle station and entering the part type and serial number into the supervisory computer. The interface necessary to perform these operations is provided using a terminal at the L/U operator station with the menu format shown below:

F1 - Fixture Availability in the Accumulator Racks

F2 - Deliver Fixture to the L/U Station

F3 - Store a Fixture in the Accumulator Rack

F4 - Request to Load Part onto Transfer Shuttle

F5 - Request to Enter Part into the FWS

F6 - Abort an L/U Terminal Operation

F7 - Acknowledge

The operator therefore has the flexibility to perform all necessary functions at the L/U station, including storing and retrieving empty fixtures from the accumulators and aborting any selected operation.

If a fixture is available, the supervisory computer automatically dispatches the AGV to retrieve the fixture and load it onto the selected transfer shuttle station. If no fixture is available, a message on the L/U terminal prompts the operator to have a new fixture brought in from outside the System. The operator uses the jib crane to lift the part, and if necessary the fixture, onto the transfer shuttle. Once the part is properly oriented in the fixture, the operator clamps the part in place by manually tightening the fixturing jigs. The operator then selects F5 to enter the part type and serial number into the Part Frame record. The Part Frame record contains the serial number, the part type, the pallet number, the entering time and date, and the robotic welding program name. This provides traceability of the parts within the System. In addition, a Part Audit record is created at this point. The Part Audit record is used to keep a history for each part as it is processed. This record contains the part serial number, the station number (added as each station is completed), the time in and out of each station, and the status of the part as it leaves each station.

If the fixtured part is residing at position number one, the operator must shift the transfer shuttle right, to bring the part to the AGV access (center) position (refer to Figure 11). The operator accomplishes this, and turntable rotation moves, by using a control panel at the L/U operator station (refer to Figure 12). When a new part is entered into the Part Frame record, an Operation Complete tag is set in the supervisory control system for the L/U station. When the preheat furnace charge table is empty, a Station Available tag is set for the preheat furnace. This valid combination of Operation Complete and Station Available tags is the condition that prompts the supervisory control system to generate AGV move commands for part movement within the FWS. This move command is then compared to other possible moves using a priority record. Upon becoming the highest priority move, the AGV is dispatched to perform the physical part transfer. This process of generating move commands and determining move priorities is called a move scan.

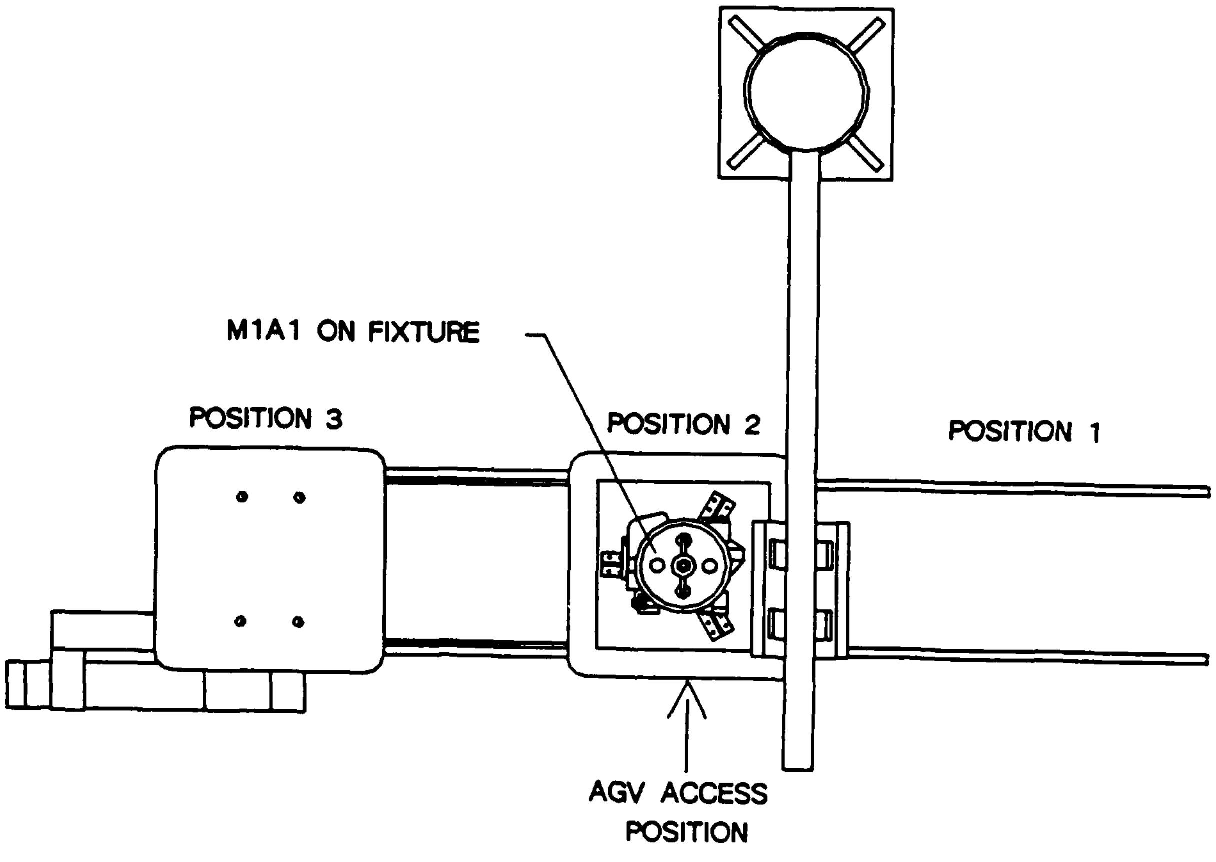

Figure 11. L/U transfer shuttle

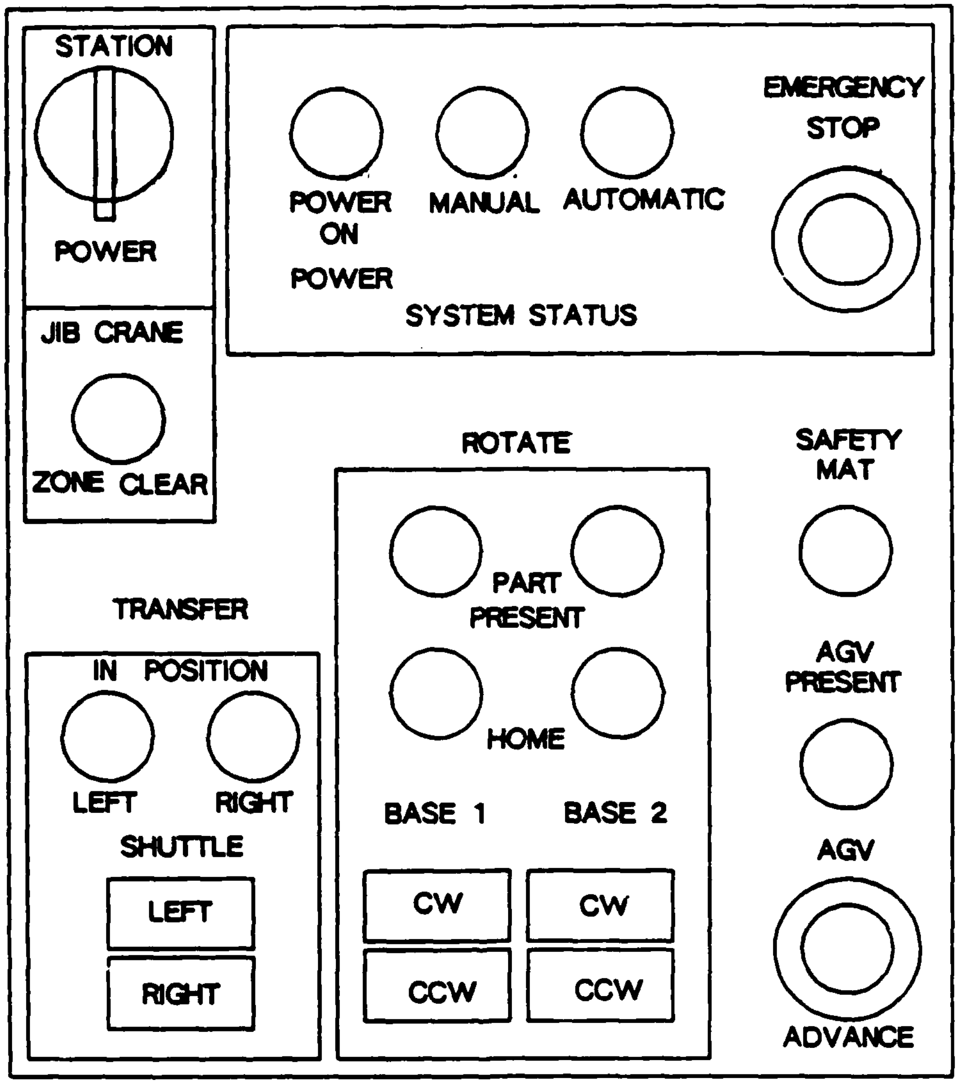

Figure 12. L/U control panel

When the AGV arrives at the L/U station, it stops at the perch position (refer to Figure 13). The perch position is located along the AGV guide path, outside of the transfer shuttle's work envelope. This perch position provides a point for the AGV to pause until the L/U operator indicates, by holding down a push-button at the operator station, that the AGV may proceed with the pickup operation. During this operation, the operator must continue to depress the AGV advance push-button as well as remain clear of the transfer shuttle (i.e. stay off of the safety mats), or the AGV pickup will be halted. After pickup, the part is brought to the preheat furnace charge table and dropped-off onto the cross transfer device.

The part is placed onto the cross transfer device by the AGV utilizing the positioning pins for accurate part placement (refer to Figure 14). During the move scan the supervisory

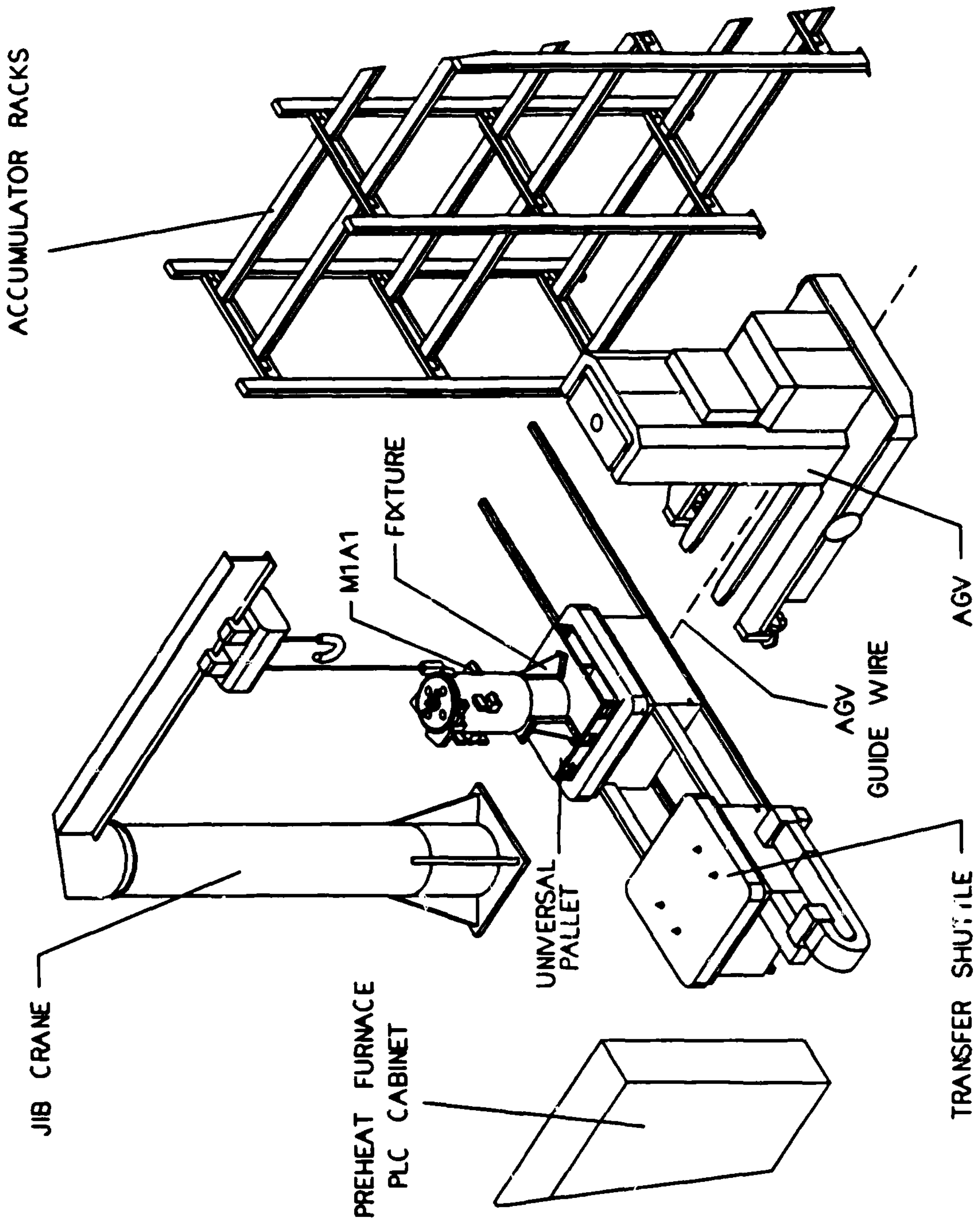

Figure 13. AGV at L/U station perch position

computer will have determined the proper furnace side on which the parts will be batched. Based upon this information, the cross transfer device will either set the part down on side one, or transfer the part to side two (refer to Figure 15). The part is then advanced as far as possible into the furnace and the Preheat timer is set. The Preheat timer is set based on the particular part's soak time stored in the Preheat record. Upon completion of the Preheat timer, the part is at the proper preheat temperature and the preheat furnace operation complete tag is set.

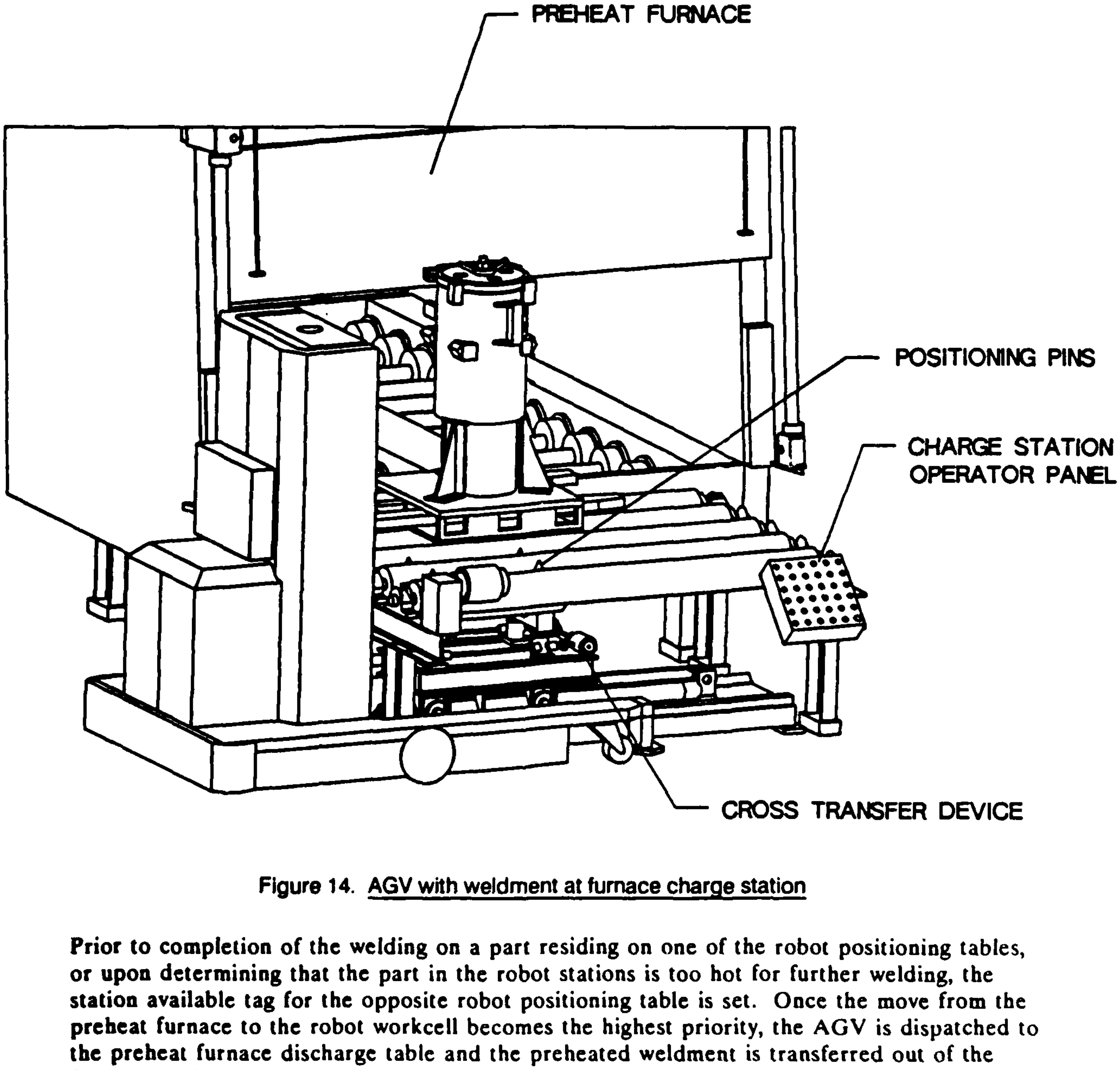

Figure 14. AGV with weldment at furnace charge station

Prior to completion of the welding on a part residing on one of the robot positioning tables, or upon determining that the part in the robot stations is too hot for further welding, the station available tag for the opposite robot positioning table is set. Once the move from the preheat furnace to the robot workcell becomes the highest priority, the AGV is dispatched to the preheat furnace discharge table and the preheated weldment is transferred out of the furnace to the AGV access point.

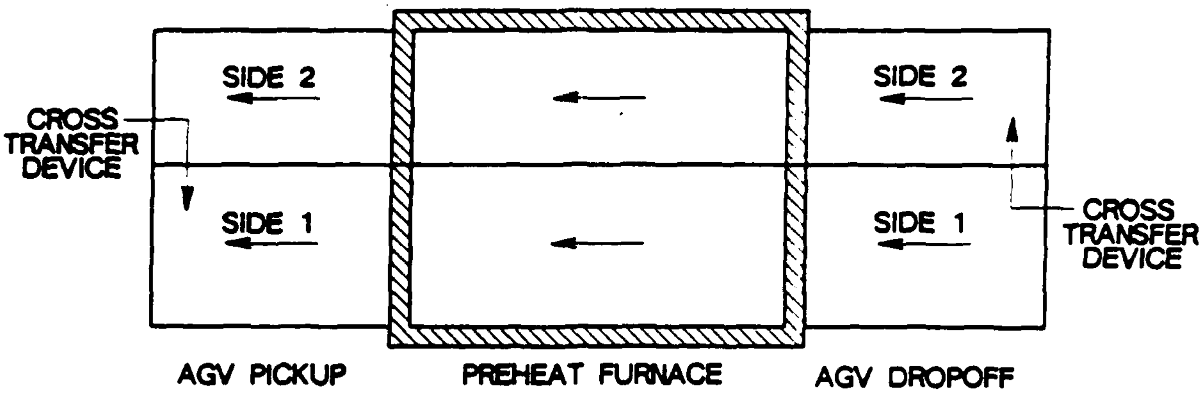

Figure 15. Part movement through preheat furnace

Upon arriving at the robot station perch position with the part, the AGV stops and waits for entry approval (refer to Figure 16). The supervisory computer sets the robot station drop-off tag and waits for the permission-to-enter signal from the safety PLC. After entry approval is granted, the AGV lowers the part onto four tapered pins, on the positioning table, until the part presence sensors verify that the weldment is in place. The part is then clamped to the positioning table by hydraulic swing clamps and the AGV returns to the perch position.

When the robot is ready to perform welding on the part, the robot controller compares the title of the weld program that is active in memory with the part type that is sent by the supervisory computer, to determine if a new program is needed. If necessary, a new program is automatically loaded from a memory bank into active memory. After the proper program is available, the supervisory computer controls the order of the robotic welding by issuing weld sequences, in the order they are to be performed, from a Weld Sequence Listing record. The supervisory computer's logic capabilities can then be used to provide flexibility during the welding operation. This allows entry and exit sequences to be issued, to handle anomalous conditions (such as running out of weld wire or tracking out of joint), without operator intervention. In addition, this allows status information about each weld sequence to be kept in a Weld Progress record. This status information serves two functions. Primarily it enables historical information to be kept about each weld, and secondly it allows sequences to be skipped over, as a result of being above the interpass temperature tolerance range, and welded after they cool.

The supervisory computer then downloads a frame alignment sequence number which aligns the robot with that particular positioning table. The first sequence number of the welding program is then issued. This first sequence is a temperature monitor sequence. The temperature monitor sequence directs the robot to replace the welding torch with an infrared pyrometer at the torch change station (refer to Figure 17). The robot then positions itself at the first temperature monitor point (Weld seams are grouped based on physical proximity, with each group having one temperature monitor point). The temperature of the weld is then read by the supervisory computer through the remote I/O monitor. This recorded temperature is then compared against an Interpass Temperature record. If this area is within the preheat temperance tolerance, the supervisory computer proceeds to issue weld sequence numbers. As each weld sequence number is received, the robot sends an acknowledgement,

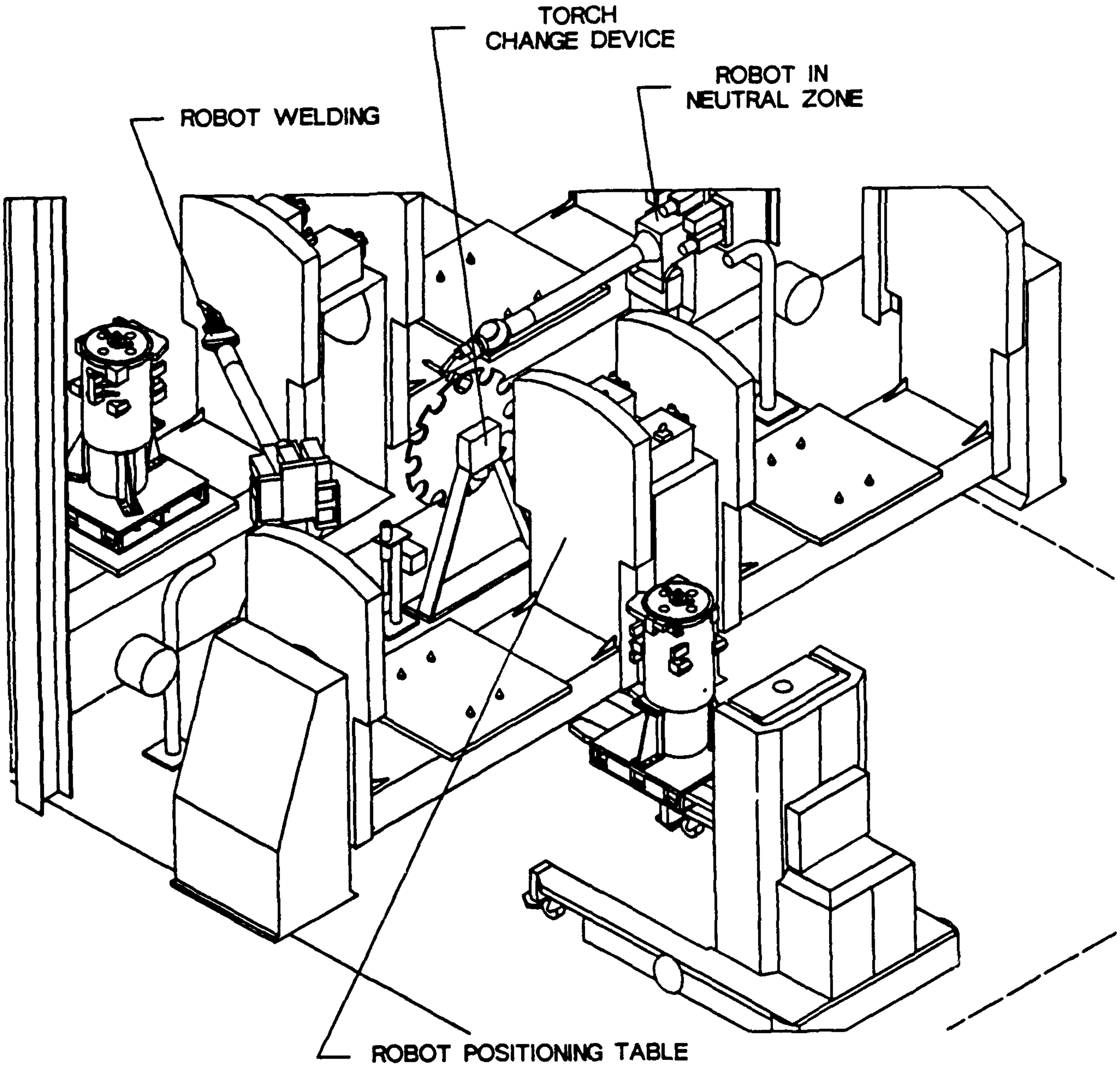

Figure 16. AGV at robot station perch position

performs the weld, and issues a status value back to the supervisory computer. This progression proceeds with the temperature monitor sequences and the welding sequences until the part is complete or no additional welding can be performed. If, during a temperature monitor sequence, any weld area is found to be too cool, the weld sequence group associated with that temperature is skipped. The supervisory system issues an exit sequence, to clear the robot from the part, and the next temperature monitor entry sequence is sent. The next temperature monitoring step is performed in the same fashion. If three areas are found to be below the required temperature, the part is designated as being too

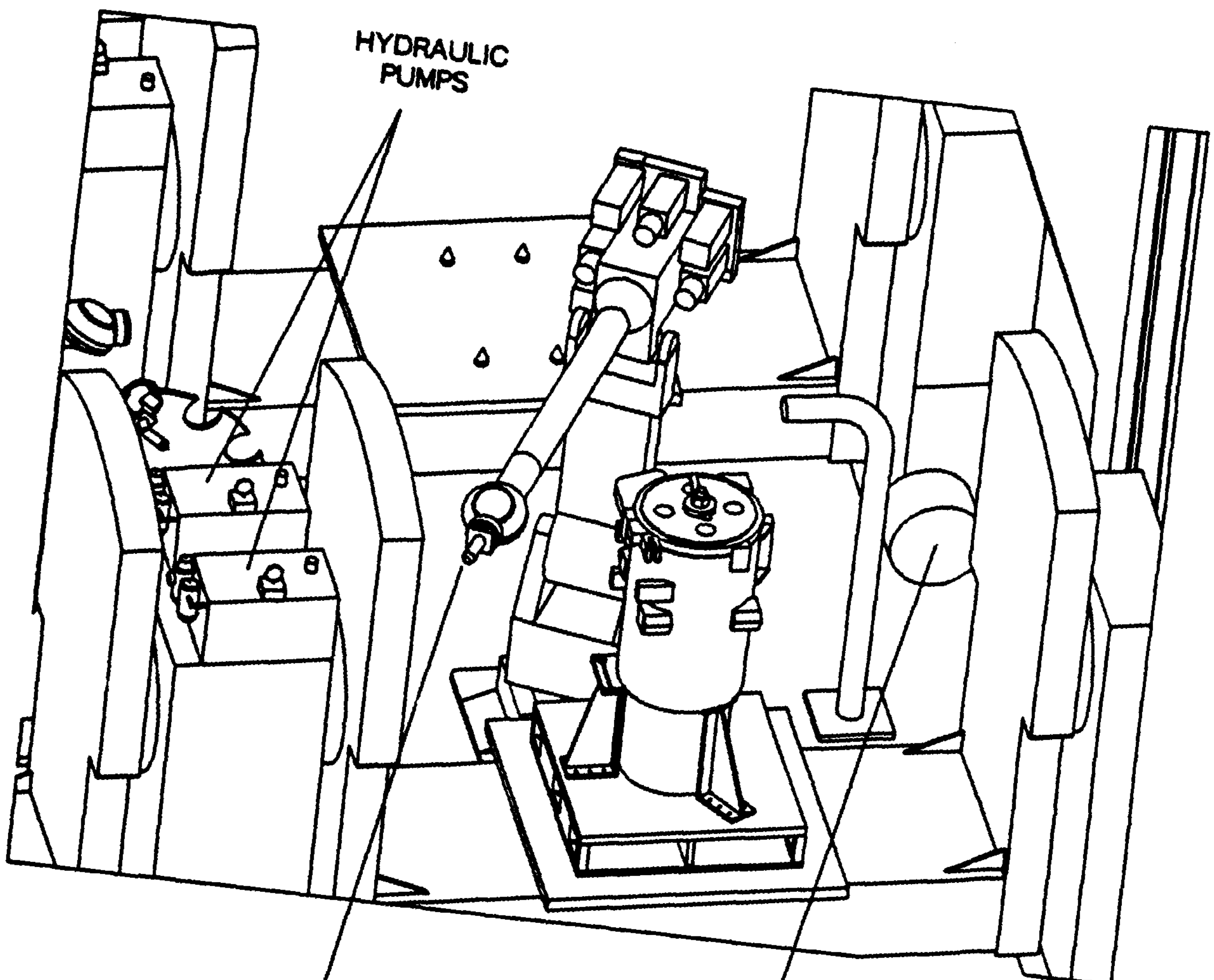

Figure 17. Robot with infrared pyrometer

cool and will then be re-routed back to the preheat furnace. If, during the robotic welding, three areas are found to be over the required temperature, the part is designated as being too hot. At this point the length of time required for the part to cool into the tolerance range is found in the Over-Temperature Cool-Down record. Based on this time, a determination is made by the supervisory computer on whether to wait at that point for the part to cool, or to move to the opposite positioning table and perform welding on another part. If the decision to switch tables is made, the robot will weld on the opposite part until the preset cool-down time for the "too hot" part passes (refer to Figure 18). At this point, the supervisory computer will instruct the robot to switch back to the previous part and finish the welding.

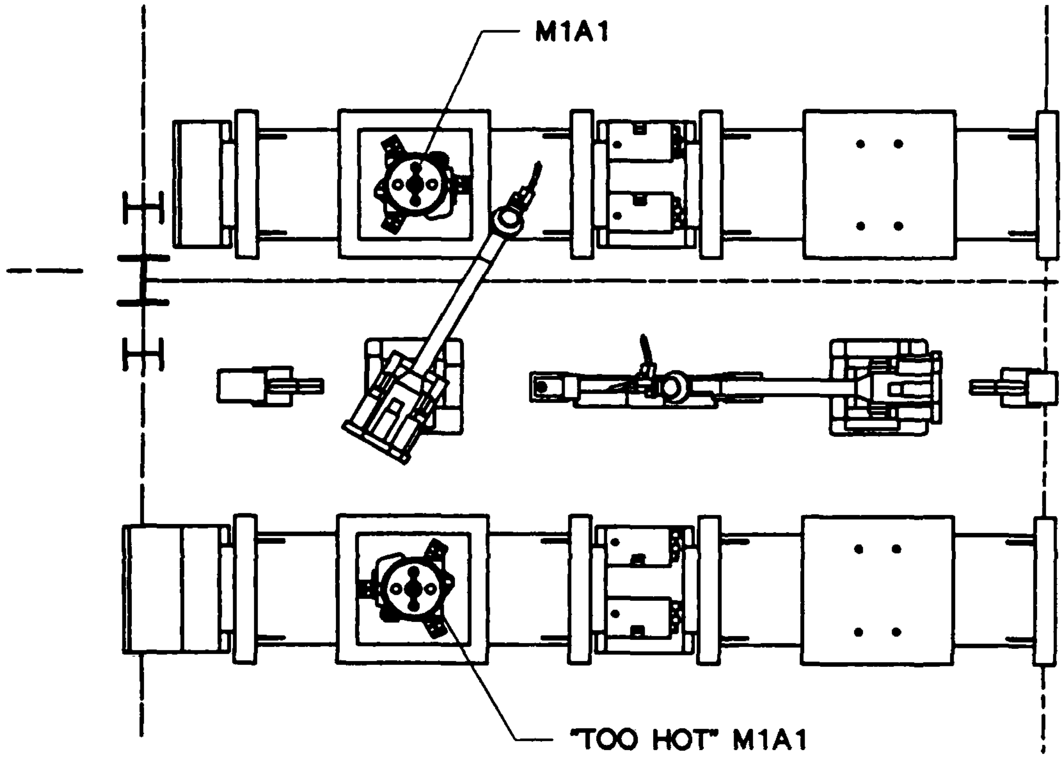

Figure 18. Robot performing welding while part cools

After the robotic welding operation is complete, the supervisory computer sets the Operation Complete tag for that robotic station. The Move Scan then selects an open accumulator rack position and designates the move from the robot station to the accumulator racks as valid. Once this move becomes the highest priority, the AGV is dispatched to the robotic station perch position. At the perch position, the AGV waits for entry approval and the supervisory computer sets the Robot Station Pickup tag. Upon determining that all conditions are normal for part pick-up, the safety PLC issues a permission-to-enter signal to the supervisory computer. The AGV then enters the station, performs the pickup operation, and transports the weldment to the selected accumulator rack position.

At the accumulator position the AGV drops-off the part and the part cool-down timer is set. The cool-down timer is based on times for each part stored in the Cool-Down record. After the part has cooled sufficiently for manual inspection, (based on the timing out of the cool-down timer) the supervisory computer sets the Operation Complete tag. Upon the I/R station becoming available and the move from the accumulator position to the I/R station becoming the highest priority, the AGV is dispatched to that accumulator rack position. At the accumulator rack, the AGV performs the pickup operation and transports the weldment to the proper I/R station perch position (refer to Figure 19).

Once the AGV arrives with the part at the I/R station perch position, the I/R operator must depress the AGV advance push-button at the QC computer console to allow the AGV to complete the drop-off. Once the part is lowered onto the positioning pins and clamped, the AGV exits the I/R area. The visual inspector then selects Visual Inspection from the QC computer menu. The QC computer sets the Ready-to-Inspect tag and the supervisory

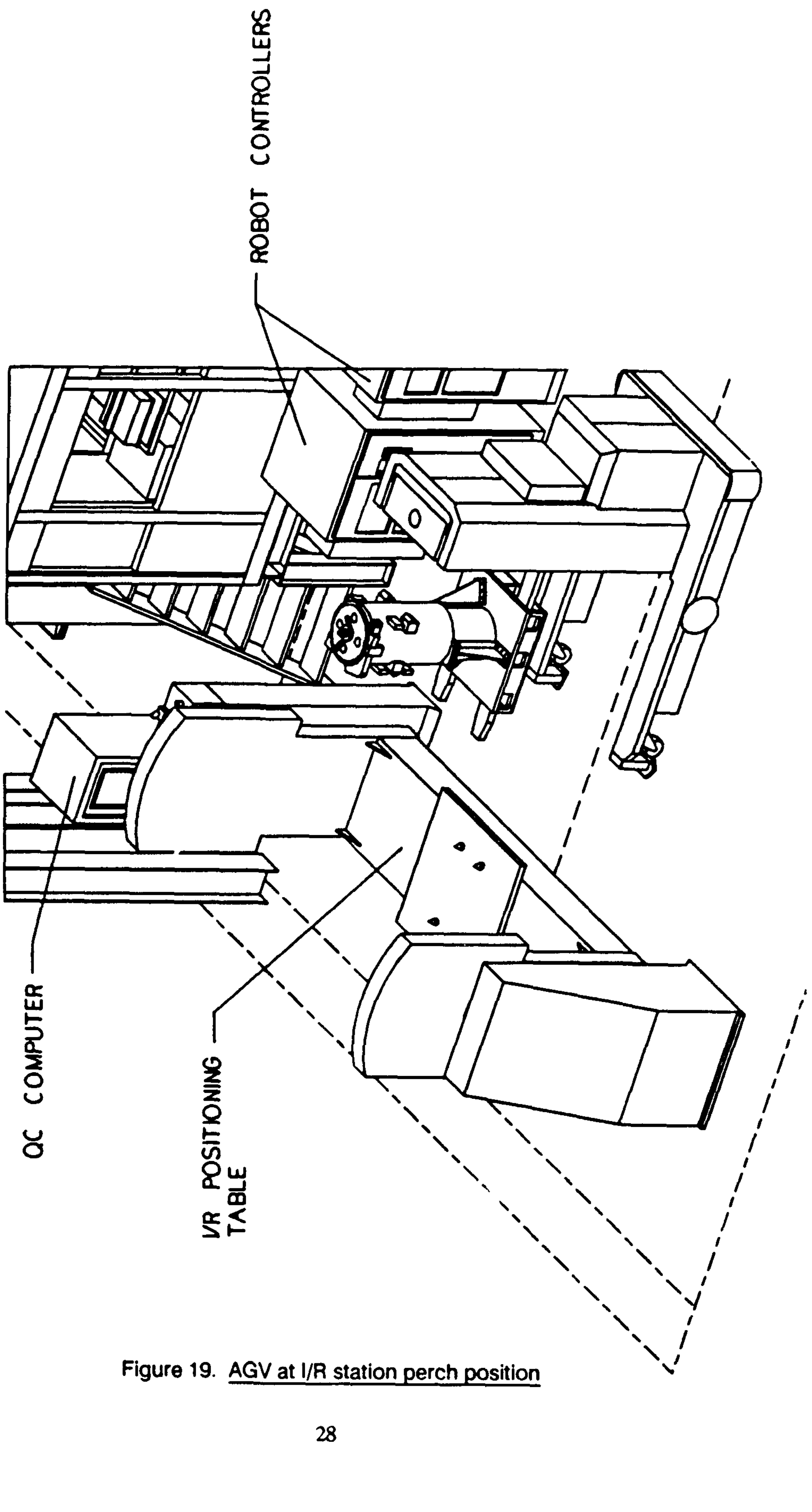

Figure 19. AGV at I/R station perch position

computer designates to the QC computer which part type's parameter file to load. The parameter file contains data for positioning, and screen graphics used in the I/R process. The first view of the part is displayed on the QC computer terminal and the operator acknowledges the part type. The operator then performs the visual inspection using the teach pendant to enter inspection data and to recall the stored positioning table positions. Each new position corresponds to a graphical representation that is displayed at the QC computer terminal (refer to Figure 20). The magnetic particle inspection and weld repair operations are performed in the same manner. During weld repair, the positioning table is only manuevered to those welds that have been designated as being defective during the inspection operations. Upon being repaired, these welds are then re-inspected until complete. The I/R results are stored on the QC computer hard disk and can then be transferred to permanent magnetic media for future recall.

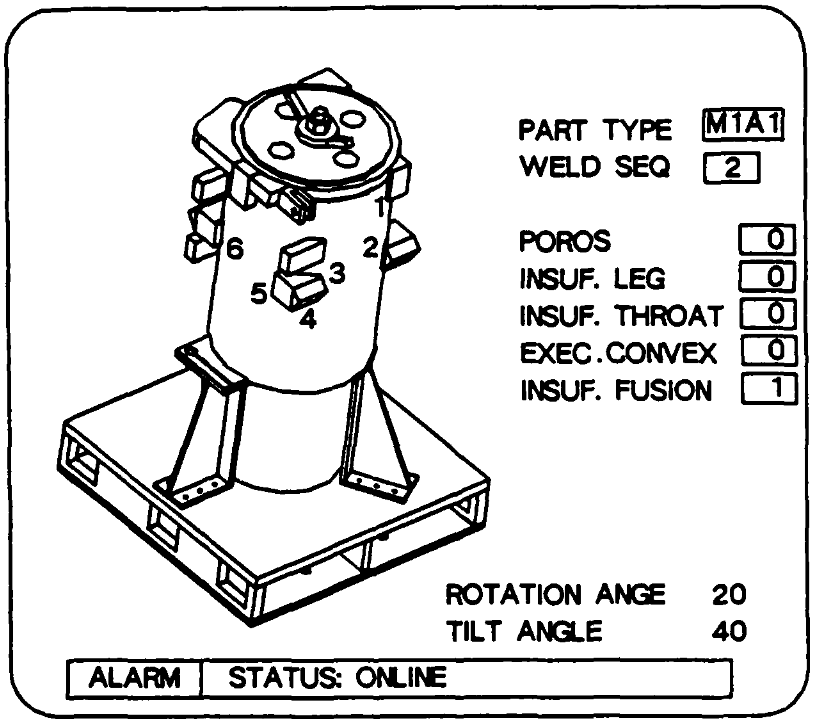

Figure 20. AGV at I/R station perch position

Upon completion of the I/R process, the operator signals the supervisory computer from the QC computer. The supervisory computer then sets the Operation Complete tag for that station and, when a station is available at the L/U station, immediately dispatches the AGV to retrieve the part from the I/R station and bring it to the L/U station. This operation happens immediately because the move from the I/R stations to the L/U stations are the highest priority moves in the move scan.

At the L/U station the operator must hold down the AGV advance push-button and remain clear of the drop-off operation, until the AGV has dropped-off the part and is back at the perch position. At this point the part can be de-fixtured by the operator and lifted, using the jib crane, into the targetting fixture. If the fixture is the correct part type, it can then be used on the next part in the System. If it will not be used immediately but will be needed soon, the fixture can be stored temporarily in the accumulator racks. If this particular part

type's processing is completed or if the allocated temporary storage space is full, the supervisory system will advise the operator to remove the fixture from the System. The operator then performs the layout inspection and sets the part at the outgoing area to be removed from the System.

In Summary, the general work sequence is as follows:

- Load/unload transfer table for fixturing
- AGV transport to the preheat furnace charge station
- Weldment preheat
- AGV transport to one of the robot positioning tables
- Robotic welding
- AGV transport to the accumulator racks
- Post welding cool-down
- AGV transport to the Inspect/Repair (I/R) station
- Visual inspection
- Magnetic particle inspection
- Weld repair
- Visual re-inspection
- Magnetic particle re-inspection
- AGV transport to the load/unload transfer table for de-fixturing
- Layout operation in the targeting fixture
- Removal from the System

4.0 CONCLUSIONS

This System Overview report, the Design Specifications Volume, the Supporting Information Document, and the Drawing Package comprise the final TDP for the contract "Design of a Flexible Robotic Arc Welding System". The TDP incorporates all the design work and serves as the final, complete design package.

The FWS comprises the state-of-the-art in welding manufacturing technology. All elements of the design have been successfully implemented in manufacturing environments with various levels of integration, however, a fully integrated system is a new opportunity. Based on this design, the FWS is a feasible approach to the processing of carbon steel weapons components.

This System allows for complete, timely cost control and production scheduling, along with historical tracking of quality and productivity data. Incorporation of these elements allows for improved cost control, and enhanced overall quality to ensure competitiveness in the future. Additionally, to prevent the obsolescence of this System, it has the capability to be upgraded to incorporate new technology elements on an as needed basis, such as vision-based seamtracking for aluminum parts, and off-line programming for the addition of new parts.

This system design has many "hard to quantify" benefits which must be incorporated in the cost justification of a flexible manufacturing facility such as the FWS. These benefits include elements such as:

- The ability to process new parts in the future,
- The capacity to handle surge requirements (2.5 times normal the one shift production),
- The minimization of necessary floor space (7 manual weld booths versus 21),
- The decreased work-in-process,
- The decreases in indirect labor (such as reduced inspection times), and
- The decreased re-work, due to increased consistency and quality tracking.

Implementation of this System would provide RIA the opportunity to modernize their welding manufacturing process and to support a showplace facility. Additionally, development of this facility would provide the Army the ability to transfer technology to other facilities and other products, as well as provide personnel exposure to state-of-the-art manufacturing equipment.

ACRONYM LIST

A-B	Allen-Bradley
ADPL	Accumulator Destination Priority List
AGV	Automatic Guided Vehicle
AISC	American Institute of Steel Construction
ASCII	American Standard Code for Information Interchange
ASTM	American Society for Testing and Materials
AWS	American Welding Society
BCS	Base Control Software
CCD	Charge Coupled Device
CCTV	Closed Circuit Television
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CRT	Cathode Ray Tube
DAC	Digital-to-Analog Conversion
DH+	Data Highway Plus
EGA	Enhanced Graphics Adaptor
EMI	Electromagnetic Interference
EPROM	Electrically Programmable Read-Only Memory
FWS	Flexible Welding System
GMAW	Gas Metal Arc Welding
GPRIO	General Purpose Remote I/O
HDM	Historical Data Management
HP	Horsepower
HWDC	Half-Wave Direct Current
I/O	Input/Output
I/R	Inspection/Repair
L/U	Load/Unload
LCD	Liquid Crystal Display
MIG	Metal Invert Gas
MS-DOS	Microsoft-Disk Operating System
NEMA	National Electrical Manufacturers Association
OCT	Operation Complete Toggle
OSHA	Occupational Safety and Health Administration
PAU	Position Analog Unit
PC	Personal Computer
PIC	Part Identification Code
PLC	Programmable Logic Controller
QC	Quality Control
RAM	Random Access Memory
RF	Radio Frequency
RFI	Radio-Frequency Interference
RIA	Rock Island Arsenal
SAT	Station Available Toggle
SMAW	Shielded Metal ARC Welding
SPC	Statistical Process Control
SWP	Servo Workpiece Positioner
TCP	Tool Center Point
WFS	Wire Feed Speed

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